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USER'S MANUAL FOR UCIN-CABLE III

A TWO-DIMENSIONAL, FINITE SEGMENT COMPUTER CODE FOR SUBMERGED AND PARTIALLY SUBMERGED CABLE SYSTEMS

Ronald L. Huston, Professor of Mechanics
Department of Mechanical and Industrial Engineering
University of Cincinnati
Cincinnati, Ohio 45221

James W. Kamman, Assistant Professor
Department of Aerospace and Mechanical Engineering
University of Notre Dame
Notre Dame, Indiana 46556

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June 1984

This report has been prepared with the partial support of the NAVY/ASEE Summer Faculty Research Program.

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NAVAL COASTAL SYSTEMS CENTER
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ADMINISTRATIVE INFORMATION

This report documents the capabilities, theoretical basis, and instructions for use of the cable dynamics computer program UCIN-CABLE III. The work was performed at NCSC (Hydromechanics Branch, Code 4210) and was supported by the ASEE Summer Faculty Research Program and NCSC IR/IED funds.

Released by
R. S. Peterson, Head
Hydromechanics Branch

Under authority of
D. C. Summey, Head
Vehicle Technology Division

USER'S MANUAL

FOR

UCIN-CABLE III

A Two-Dimensional, Finite Segment

Computer Code for Submerged and Partially

Submerged Cable Systems

James W. Kamman

Assistant Professor

Department of Aerospace and Mechanical Engineering

University of Notre Dame

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Ronald L. Huston

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Department of Mechanical and Industrial Engineering

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents a User's Manual for the computer program UCIN-CABLE III. The program is designed to predict the two dimensional dynamics of submerged and partially submerged towing cable systems. A towing cable system includes the towing cables as well as a set of towed bodies. The system may have one or many branches, but no closed loops may be formed.

The cable is modeled as a series of rigid cylinders connected end to end by hinge joints. The fluid forces on each segment include the effects of (over)

20. ABSTRACT (continued):

normal and tangential drag, added mass, and buoyancy. The fluid forces on the towed bodies are calculated from a set of 25 hydrodynamic coefficients. These account for fluid drag and added mass effects. Byoyancy forces are included separately.

This manual provides instruction for using CABLE to study such cable systems. It also provides sample input and output data.

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I. SUMMARY

This is a User's Manual for the computer program UCIN-CABLE III. The program is designed to study the two dimensional dynamics of submerged and partially submerged towing cables. The cables themselves may have multiple branches. Figure 1 shows a schematic illustration of a typical cable system. The system

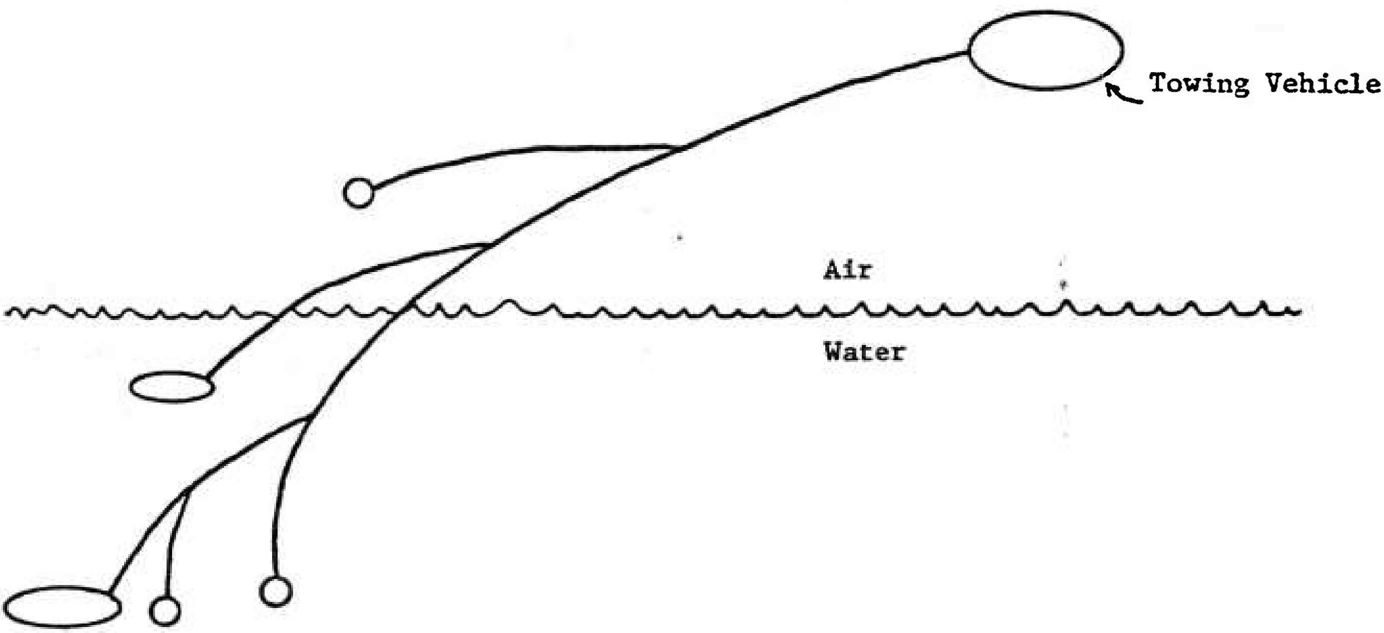

Figure 1. A Typical Multiple Branch Cable System.

can, of course, be much simpler than that shown in Figure 1. For example, it could consist of a single cable segment as with a buoy or balloon mooring system as depicted in Figure 2.

I. Summary

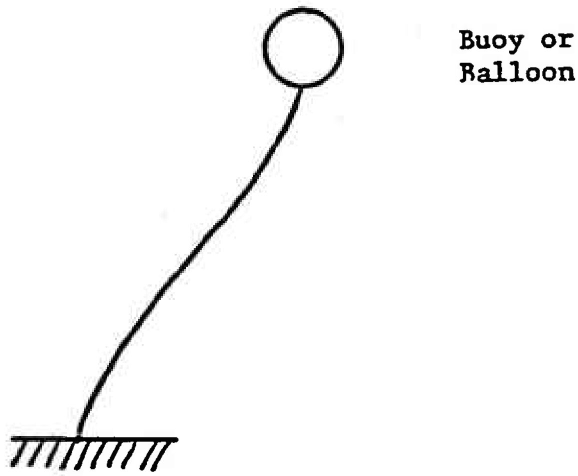

Figure 2. A Simple Mooring System.

The manual provides instruction for using CABLE to study such cable systems. It also provides sample input and output data. The computer program itself is written in FORTRAN. Hence, the input requirements are in the FORTRAN format.

II. CAPABILITIES OF CABLE

CABLE is designed to perform the following dynamic analyses: Given: a) the physical data of the cable (weight, diameter, length) and the physical data of the towed body; b) the configuration of the cable branches; c) the fluid properties; d) the motion of the towed end of the cable; and e) the initial configuration of the cable system; then the program determines the kinematics (position, velocity, and acceleration) at the various points of the cable system as well as the cable tension.

CABLE provides the user with the following options:

1) Either English or metric units may be used.

2) The cable system may be immersed in two fluid media - normally air and water.

3) The fluid media may be given a uniform "stream" velocity.

4) Fluid forces may be applied to the cable system. These forces include:
   a) Normal drag forces
   b) Tangential drag forces
   c) Added mass forces due to the cable system acceleration
   d) Buoyancy forces

   These fluid forces may be partially or totally neglected.

II. Capabilities of CABLE

5) The towed end of the cable may have arbitrary motion relative to a ship frame. The ship frame itself may have motion in a straight line.

6) Gravity forces may be included or neglected.

In addition to the above options, the user may arbitrarily select the numerical integration parameters. Certain output options are also available.

III. THEORETICAL BASIS OF CABLE

The cable system is modelled by a series of cylindrical links. These links are connected in a chain to simulate the cable. Figure 3 depicts such a modelling. The number of links, and hence, their length, is a user option.

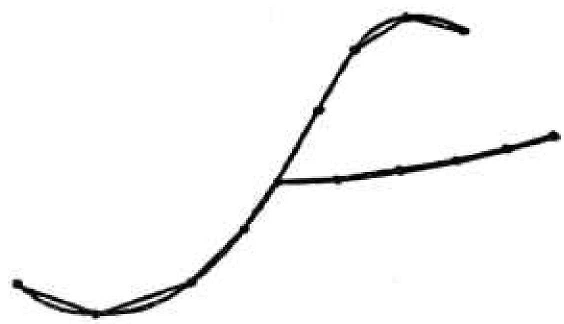

Figure 3. A Finite-Segment Model of a Cable.

The model of Figure 3 is a "finite-segment" model of the cable. As such, it forms a "general-chain" system or an "open-tree" system. References [1-3]* provide an analytical basis for studying these systems. The governing differential equations are obtained using Lagrange's form of d'Alembert's principle and Kane's equations as exposited by Kane and others [4-8]. This procedure has distinct advantages over Newton's laws and Lagrange's equations for analyzing multibody systems. Specifically, Kane's method provides for the automatic elimination of nonworking internal constraint forces while avoiding the tedious differentiation of scalar energy functions.

* Numbers in brackets refer to References at the end of the manual.

III. Theoretical Basis of CABLE

In the formulation of CABLE, the velocities and accelerations are computed through vector derivatives which may be evaluated through vector cross products. This leads to algorithms which are readily converted into computer subroutines.

The fluid forces on the CABLE system are computed using procedures outlined in References [9, 10, 12-15]. These include inertia ("added mass"), drag (normal and tangential for cable links), and hydrostatic (buoyancy) forces. They are represented by forces passing through the mass centers of the members of the cable system together with couples.

Finally, the governing equations are solved, using RKGS [11], a fourth-order Runge-Kutta numerical integrator. CABLE is written, however, so that other numerical integrators may also be used.

IV. DEFINITIONS OF TERMS

This part of the Manual defines the terminology used in CABLE. These definitions are useful in understanding the input requirements. Underlining is used to further identify terms of interest.

1. Cable Model

Figure 4 shows a finite-segment cable model of a cable system.

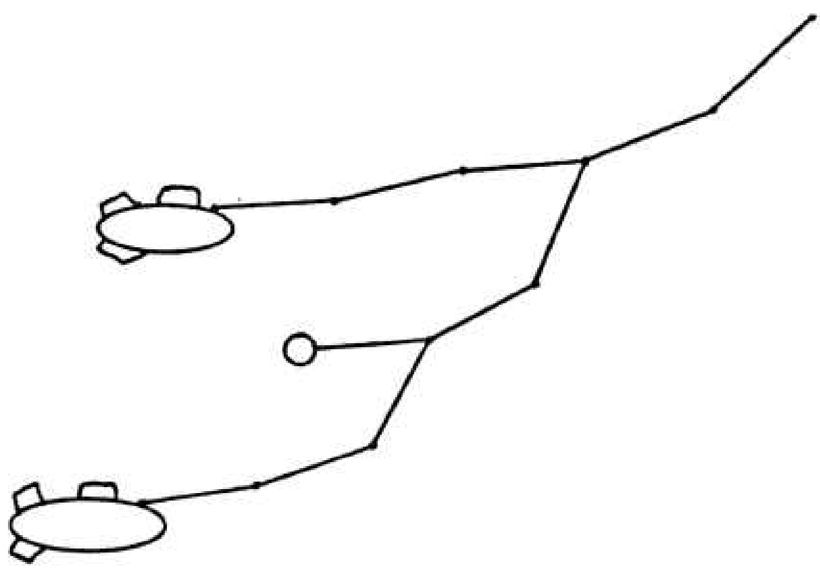

Figure 4. A Finite-Segment Model of a Cable System.

It consists of a series of cylindrical cable links connected in "tree-like" fashion such that no closed loops are formed.

IV. Definitions of Terms

2. Cable Link System

A cable link system is a set of connected cable links together with the towed bodies as shown in Figure 4. Thus, a cable link system is a multibody system as defined in References [2, 3].

3. Cable Link

A cable link is an individual member of a cable link system (aside from towed bodies). A cable link is a rigid cylindrical rod. It is connected to adjacent links and the towed bodies by hinge joints.

4. Reference Link and Reference Points

The uppermost link of the cable link system is called the reference link as shown in Figure 5. The upper end of the reference link is called the system reference point Q. In a typical dynamic configuration of the system, Q is given a prescribed motion relative to the mean ship frame. (See Section 7 below.)

Also each of the links and the towed bodies of the cable link system has its own reference point. For the reference link, it is Q the system reference point. For any other link, say L_k, it is Q_k the joint location at the upper end of the link. For any towed body, say B_ℓ, it is Q_ℓ the joint location at the cable attach point. See Figure 5.

IV. Definitions of Terms

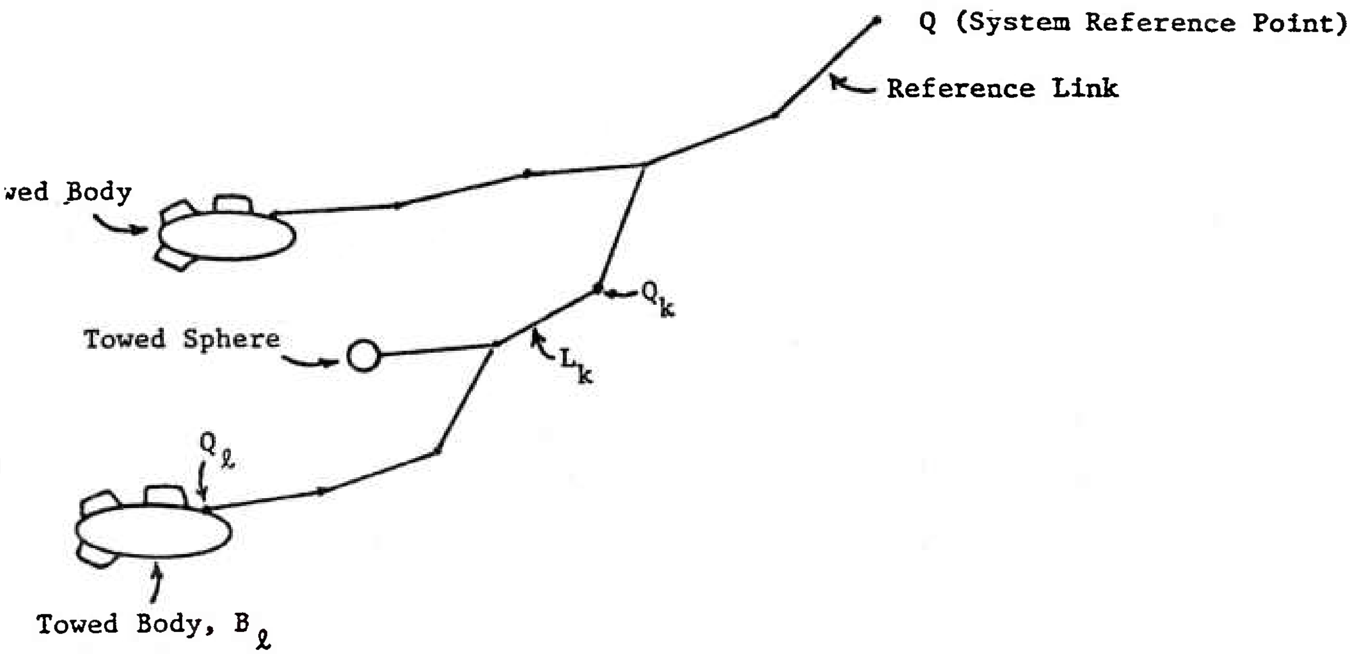

Figure 5. Reference Link, Reference Points, and Towed Bodies.

5. Towed Bodies

CABLE has provisions for handling many typical towed bodies at the ends of the branches of the cable system. These bodies fall into two general categories: 1) spheres; and 2) other more general types of forward towed bodies. CABLE refers to the former as towed spheres, and the latter as towed bodies. The towed spheres are connected to the cable links by a hinge joint at the center of the sphere. The towed bodies are attached to the cable links by a hinge joint at some reference point within the body. Neither this reference point nor the center of buoyancy of the towed body need be located at its mass center.

IV. Definitions of Terms

6. Link Connection Array

The configuration of the cable link system and the arrangement of the branches can be described by a link connection array. To develop this array, let the links of the system be numbered as follows: Let the reference link be link 1, called L_1. Next, number the remaining links, towed bodies, and towed spheres in ascending progression away from L_1 through the branches of the system. Finally, let the mean ship frame be body 0, called L_0. Figure 6 illustrates this numbering procedure for the cable system of Figures 4 and 5.

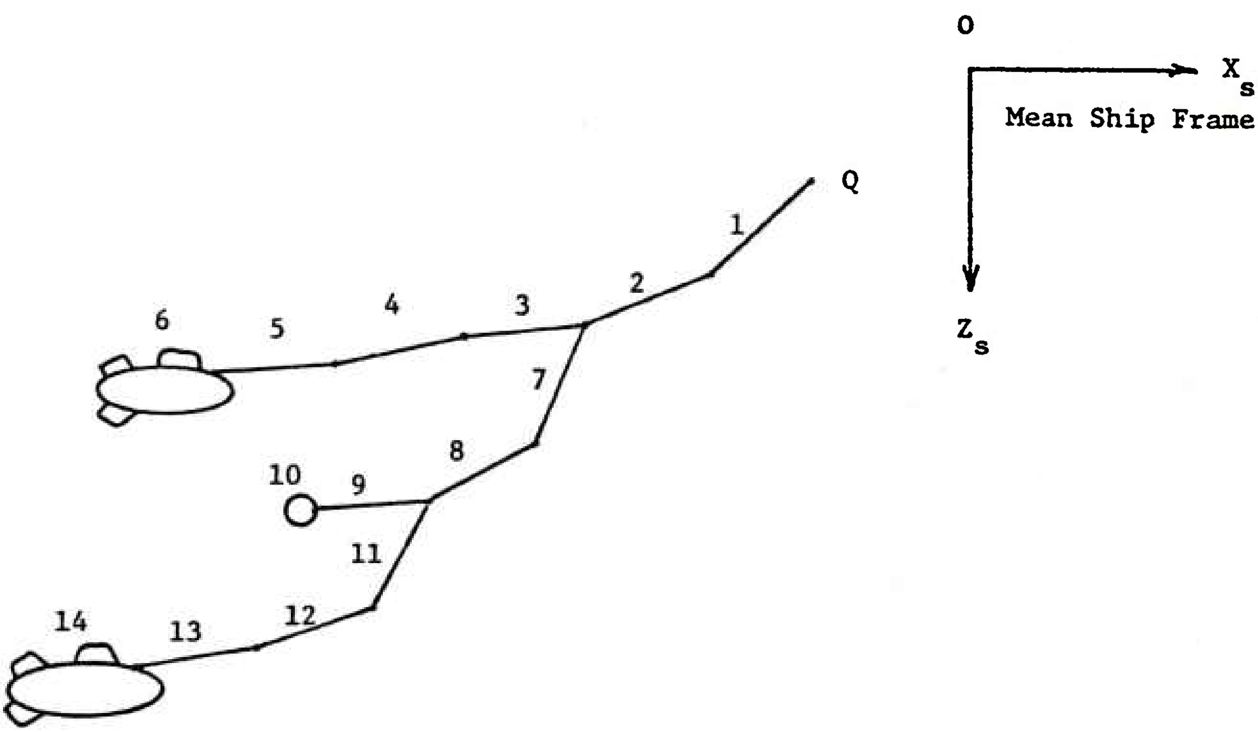

Figure 6. Numbering of the Cable Link System of Figures 4 and 5.

IV. Definitions of Terms

If the links, towed spheres, and towed bodies are numbered in this manner, each link, sphere, and towed body, except the reference link, is connected to one and only one adjacent lower numbered link. (Note, however, that a link, for example, L_2 may be connected to more than one adjacent higher numbered link.)

The array listing the lower numbered links is called the link connection array. For the system shown in Figure 6, this array is:

Link/Sphere/ Towed Body:	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Link Connection Array:	0	1	2	3	4	5	2	7	8	9	8	11	12	13

Note that the configuration of the system can be constructed once the link connection array is known. That is, there is an equivalence between the cable link system configuration and the connection array.

7. Mean Ship Frame, Inertia Frame, and Coordinate Systems

In CABLE, the reference point Q at the upper end of the reference link may be given an arbitrarily prescribed motion relative to the mean ship frame, which itself may be given a prescribed motion relative to an inertial reference frame. This is depicted in Figure 7. The mean ship frame is assumed to be rigidly attached to a towing vessel, such as a ship or a helicopter.

IV. Definitions of Terms

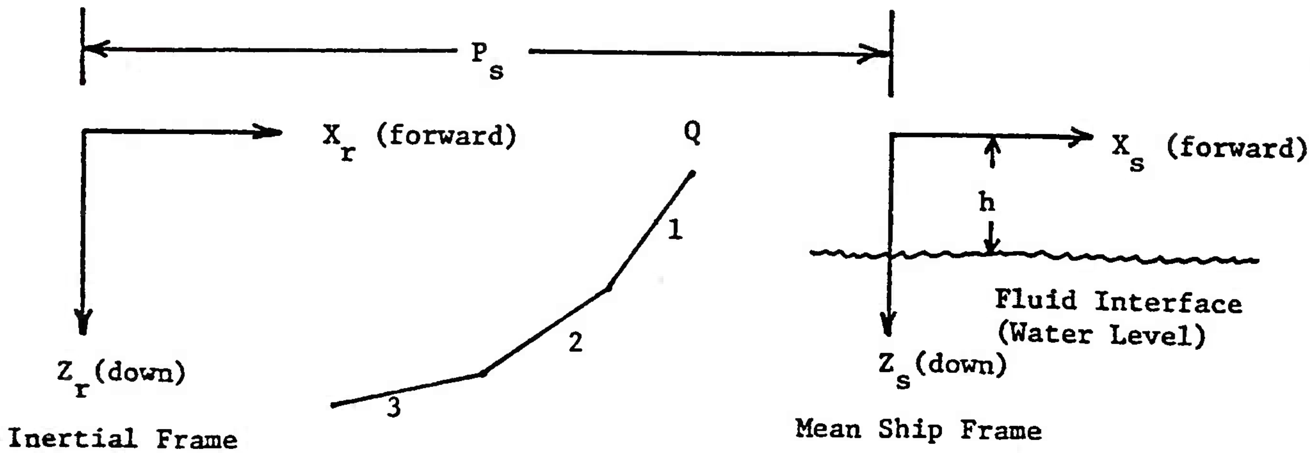

Figure 7. Inertial Frame, Mean Ship Frame, and Cable Link System.

Coordinate Systems are associated with both the mean ship frame and the inertial frame, as shown in Figure 7. In both frames, the X directions are forward, and the Z directions are vertically down. The motion of the mean ship frame relative to the inertial frame is restricted to straight line motion along X_R (or X_S). However, Q may have arbitrary motion in the X-Z plane relative to the mean ship frame.

Finally, CABLE has the option of locating the fluid interface (or water level) at any distance h below (or above, if h is negative) the mean ship frame.

8. Acceleration Profiles

The specification of the motion of reference point Q relative to the mean ship frame and the motion of the mean ship frame relative to the inertia frame

(See Figure 7) may be accomplished either by using an acceleration profile, described here, or by using a precoded function, described in the following section.

An acceleration profile is simply a set of data representing the coordinates of selected points of an acceleration-time curve. Such coordinates may be obtained from the graph of the acceleration function.

CABLE has the capability of accepting as many as 25 data points from an acceleration curve. A piecewise linear approximation is then made of the acceleration function. For example, consider the acceleration function and its approximation shown in Figure 8. The acceleration, velocity, and displacement during the i^{th} time interval are then:

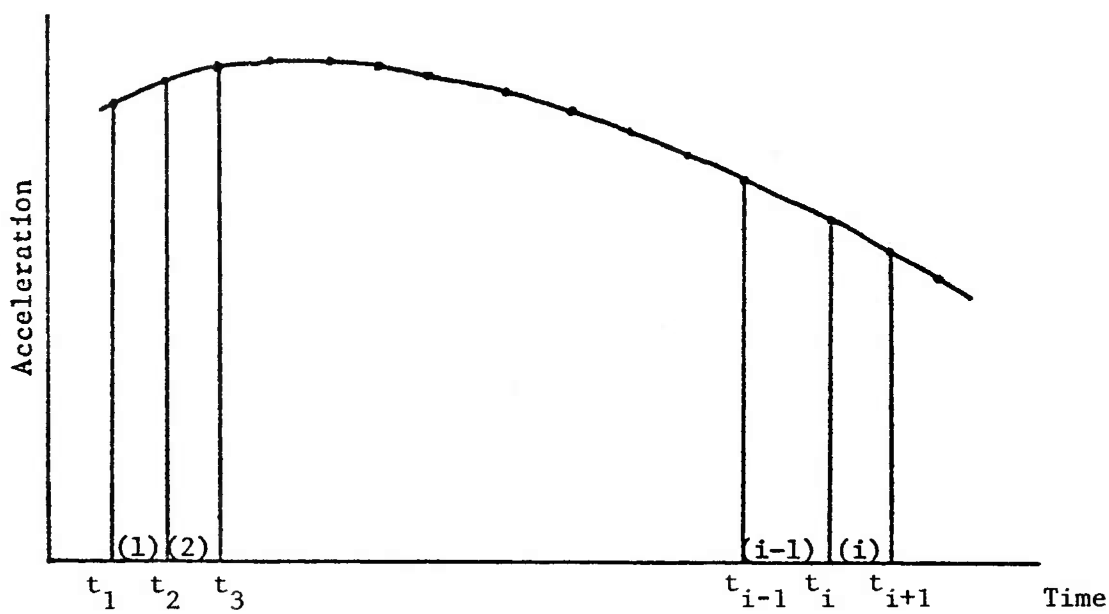

Figure 8. Acceleration Profile Approximation.

IV. Definitions of Terms

$$a = a_i + \left(\frac{a_{i+1} - a_i}{t_{i+1} - t_i}\right)(t - t_i) \tag{1}$$

$$v = v_i + a_i\,(t - t_i) + \left(\frac{a_{i+1} - a_i}{t_{i+1} - t_i}\right)(t - t_i)^2/2 \tag{2}$$

and

$$d = d_i + v_i(t - t_i) + a_i(t - t_i)^2/2 + \left(\frac{a_{i+1} - a_i}{t_{i+1} - t_i}\right)(t - t_i)^3/6 \tag{3}$$

where a_i, v_i, d_i, and t_i are the acceleration, velocity, displacement, and time at the beginning of the i^{th} interval. Thus, the entire kinematic profile (displacement, velocity, and acceleration) is known when the a_i are given, and when v_1 and d_1, the initial velocity and displacement (at time t_1), are given.

9. Precoded Functions

If the motion of reference point Q relative to the mean ship frame, or if the motion of the mean ship frame relative to the inertia frame is relatively simple, it may be convenient to describe the motion using a precoded function. For example, these functions may be used to describe constant or decaying sinusoidal speed of the mean ship frame. Specifically, CABLE provides the user with the following precoded function:

$$f = f_0 + Ae^{bt}\cos(pt + \phi) \tag{4}$$

where f_0, A, b, p, and ϕ are user supplied constants. Hence, for a constant ship speed, the user would simply provide a value for f_0 with the other values being zero (which are the default values). Specific input format is discussed in the following part of the Manual.

10. Fluid Velocities

CABLE also has the provision of allowing each of the fluids to have a uniform (constant in time and space) "stream" velocity. Specific input format is described in the following part of the Manual.

11. Link Orientation Angles

Since the motion of the cable system takes place in the X-Z plane, the relative orientation of two adjacent links or of a towed body and its adjacent link can be described by a single angle of rotation about the Y axis. Link orientation angles will be described here and towed body orientation angles in the next section.

Consider a typical cable link L_k as shown in Figure 9. Let X_k, Y_k, and Z_k represent a coordinate frame attached to L_k such that the axis of L_k is along the X_k axis as shown. Also let Y_k be perpendicular to the plane of motion completing the X_k, Y_k, Z_k right-handed system. (The circular arrow indicates that

IV. Definitions of Terms

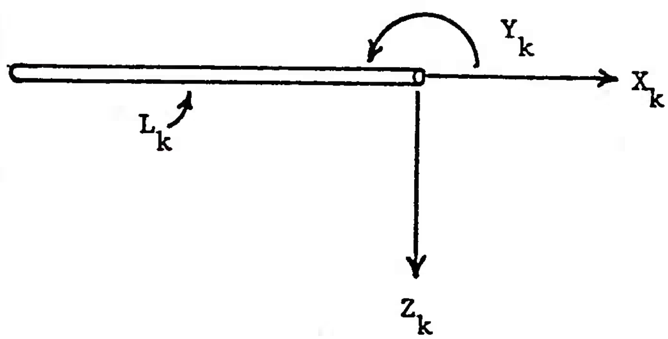

Figure 9. Typical Link L_k and Coordinate Axes.

Y_k points out of the page - the direction of advance of a right-handed screw when rotated in the direction of the arrow.) Next, consider link L_k and its adjacent lower link L_j as shown in Figure 10. Let the axes system X_j, Y_j, and

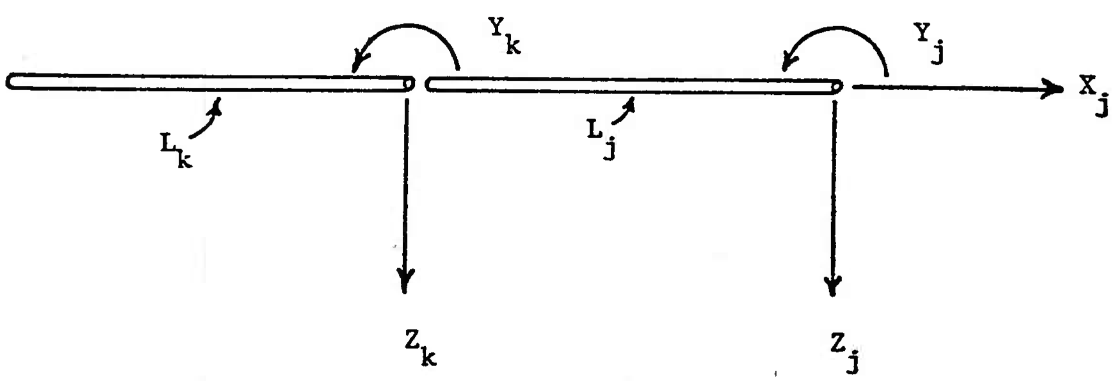

Figure 10. Two Typical Adjoining Links and Aligned Axes.

Z_j of L_j be initially aligned with the axes of L_k as shown. Now, L_k can be located relative to L_j by a single rotation about the Y_k (or Y_j) axis. The angle of rotation is taken as positive when the rotation is right-handed (or dextral)

relative to the Y axes. That is, it is positive when the rotation is in the direction of the circular arrows shown. A positive rotation angle θ_k is shown in Figure 11.

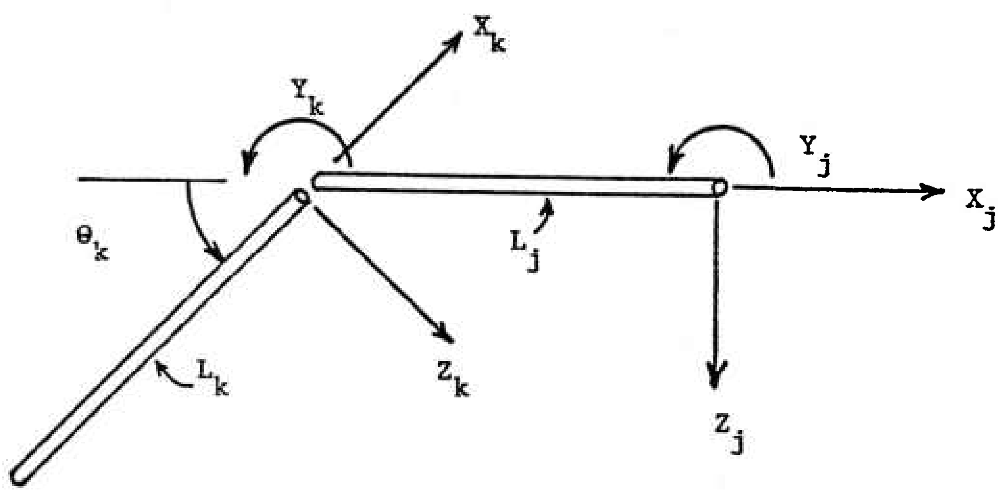

Figure 11. Positive Link Rotation Angle.

12. Towed Body Orientation Angles

The orientation of a towed body relative to its adjacent lower link is described similar to that for the cable links. Consider a typical towed body as shown in Figure 12. Let the X_k, Y_k, and Z_k axes represent a coordinate frame located at the cable attach point with the X_k axis parallel to the longitudinal axis of the towed body. As shown, the X_k, Y_k, and Z_k axes are along the axial, lateral, and normal directions of the towed body.[13] Next, consider towed body B_k and its adjacent lower link L_j as shown in Figure 13. Let the axes

IV. Definitions of Terms

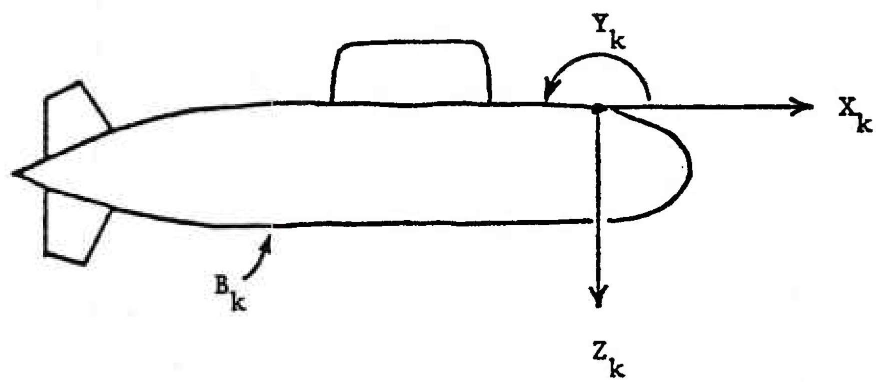

Figure 12. Typical Towed Body B_k with Coordinate Axes.

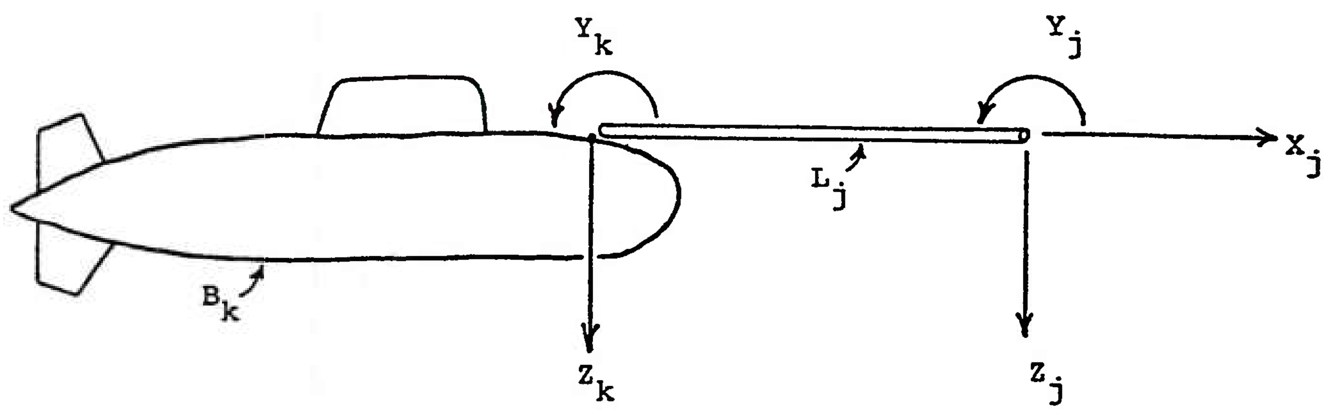

Figure 13. Typical Towed Body and Adjoining Link with Aligned Coordinate Axes.

system X_j, Y_j, and Z_j of L_j be initially aligned with the axes of B_k as shown. Now, B_k can be oriented relative to L_j by a single rotation about the Y_k (or Y_j) axis. Note that for typical configurations of the towed body , its rotation angle will be negative as shown in Figure 14.

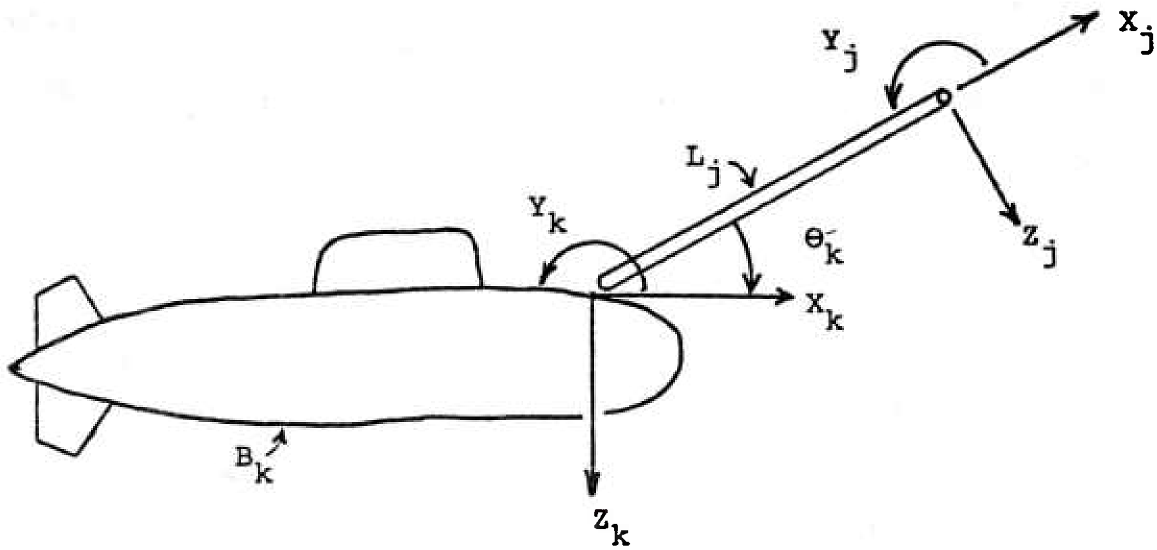

Figure 14. Typical Towed Body Configuration with Negative Rotation Angle.

13. Initial Cable and Towed Body Configuration

The initial configuration of the cable system before the equations of motion are integrated depends upon the initial values of the relative orientation angles of the links and towed bodies. For example, if the initial values of all the orientation angles are zero, the initial configuration of a single branch cable system with a towed body would be as shown in Figure 15.

IV. Definitions of Terms

Figure 15. "Zero" Initial Configuration of a Single Branch Cable with a Towed Body.

14. Weight Density, Link Length and Link Diameter

The physical parameters needed by CABLE to describe the cable links are the weight density, link length, and link diameter. The weight density is defined as the weight per unit length.

The cable links may have different lengths, diameters, and weights. That is, the cable need not be uniform in its physical properties.

When the above data are given, CABLE automatically calculates the link mass center locations and the link inertia.

IV. Definitions of Terms

15. Weight and Diameter of the Towed Spheres

In addition to the link physical parameters, CABLE also requires the physical parameters of the towed spheres. These are simply the sphere weights and diameters.

16. Towed Body Physical Data

The physical data needed by CABLE to describe the towed bodies is somewhat more extensive, since these bodies can have more general shapes. The towed body's weight, axial length, volume, inertia, mass center position vector, and buoyancy center position vector are required. The body's inertia is its mass moment of inertia about an axis perpendicular to the plane of motion, and passing through its mass center CG. The mass center position vector $\underset{\sim}{r}_G$ is specified by components of the position vector of the mass center of the body relative to the cable attach point (reference point), and the buoyancy center position vector $\underset{\sim}{r}_B$ is specified by components of the position vector of the center of buoyancy relative to the body's mass center. (See Figure 16.) In both cases, components are taken along the body-fixed coordinate axes with negative numbers indicating negative coordinate directions.

IV. Definitions of Terms

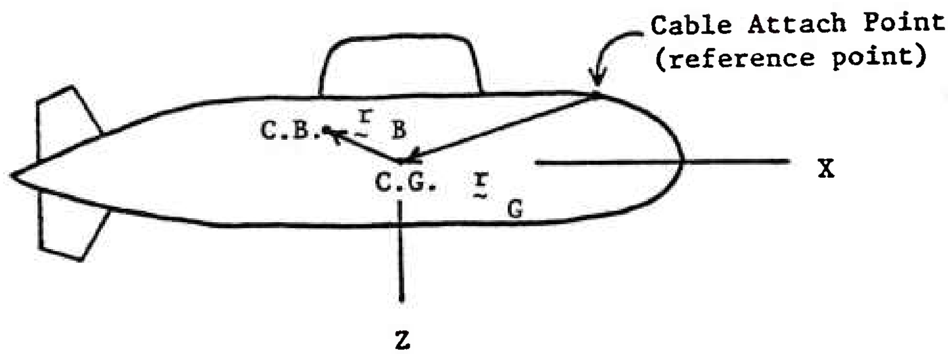

Figure 16. Typical Towed Body with Mass-Center and Buoyancy-Center Position Vectors and Body-Fixed Coordinate Axes.

17. Fluid Forces on Cable Links

CABLE has the options of including up to four kinds of fluid forces exerted on the cable links: 1) drag forces normal to the link; 2) drag forces parallel (tangent) to the link; 3) "added-mass" forces; and 4) buoyancy forces. Reference [9] describes these forces in detail.

The drag forces and the added mass forces may be defined as follows: Consider a typical cable link as shown in Figure 17. Let G_k be the center of the link, and let P be a point a distance x from G_k as shown. The added mass and drag forces at P (per unit length) may then be represented as:

IV. Definitions of Terms

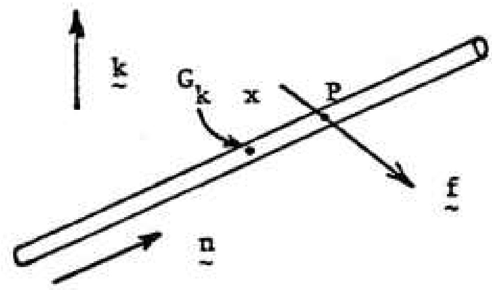

Figure 17. Fluid Force at a Typical Point of a Cable Link.

$$\underset{\sim}{f} = A\underset{\sim}{a}_N + B\left|\underset{\sim}{v}_N\right|\underset{\sim}{v}_N + C\left|\underset{\sim}{v}_T\right|\underset{\sim}{v}_T \tag{5}$$

where $\underset{\sim}{v}_N$ is the normal component of the fluid velocity relative to the cable link at P, and the coefficients A, B, and C are:

$$A = C_M\rho(\pi/4)d^2 \tag{6}$$

$$B = C_N\rho(d/2) \tag{7}$$

$$C = C_T\rho(d/2) \tag{8}$$

where ρ is the fluid mass density, and d is the diameter of the cable link. C_M, C_N, and C_T are coefficients dependent upon the Reynolds number of the fluid flow past the cable link. These coefficients are usually determined experimentally. In CABLE, the following values are used [9, 12]:

$$C_M = 1.0 \tag{9}$$

$$C_N = \begin{cases} 0.0 \text{ for } Re_N \le 0.1 \\ 0.45 + 5.93/(Re_N)^{0.33} \text{ for } 0.1 < Re_N \le 400.0 \\ 1.27 \text{ for } 400. < Re_N \le 10^5 \\ 0.3 \text{ for } Re_N > 10^5 \end{cases} \tag{10}$$

IV. Definitions of Terms

$$C_T = \begin{cases} 0.0 \text{ for } Re_T \leq 0.1 \\ 1.88/(Re_T)^{0.74} \text{ for } 0.1 < Re_T \leq 100.55 \\ 0.062 \text{ for } Re_T > 100.55 \end{cases} \tag{11}$$

where the Reynolds numbers Re_N and Re_T are defined as:

$$Re_N = \rho d |\underset{\sim}{V}_N| / \mu \tag{12}$$

and

$$Re_T = \rho d |\underset{\sim}{V}_T| / \mu \tag{13}$$

where μ is the fluid viscosity.

In Equation (5), the first term is called the "added-mass" force, the second term is called the "normal drag" force, and the third term is called the "tangential drag" force. In CABLE, the system of added mass and drag forces acting at all the points of the cable link are replaced by a single force passing through G_k together with a couple. For additional information, see References [9, 12].

The buoyancy forces are due to hydrostatic pressure forces exerted on the cable link. These forces are normal to the surfaces of the link, which is exposed to the fluid. For typical links, the resultant hydrostatic force on the link is normal to the link axis, since the ends of the link are not exposed to the fluid. For these links, the system of hydrostatic forces may be replaced by a single force $\underset{\sim}{B}_N$ normal to the link axis given by:

$$\underset{\sim}{B}_n = \rho g V_k \underset{\sim}{n} \times (\underset{\sim}{k} \times \underset{\sim}{n}) \tag{14}$$

where ρ is the fluid mass density, g is the gravity constant, V_k is the cable link volume, $\underset{\sim}{n}$ is a unit vector along the link axis, and $\underset{\sim}{k}$ is a vertical unit vector as shown in Figure 17. CABLE treats all cable links as suggested above except those at the end of a branch which has no towed sphere or towed body. For those segments an adjustment is made to the buoyancy force to include the hydrostatic forces on the exposed end.

(For additional information, see reference [9])

18. Fluid Forces on Towed Spheres

CABLE has the option of including up to three kinds of fluid forces exerted on the spheres: 1) drag forces; 2) "added-mass" forces; and 3) buoyancy forces. CABLE replaces the system of drag forces, added mass forces, and buoyancy forces by a single force passing through the mass center of the sphere.

The resultant drag force and added mass force is taken to be [12, 15]:

$$\underset{\sim}{F} = -A\underset{\sim}{a} + B\left|\underset{\sim}{V}\right|\underset{\sim}{V} \qquad (15)$$

where $\underset{\sim}{a}$ is the acceleration of the mass center of the sphere relative to the fluid, $\underset{\sim}{V}$ is the fluid velocity relative to the mass center of the sphere, and the coefficients A and B are:

IV. Definitions of Terms

$$A = \tfrac{1}{2} C_M \rho V_S \tag{16}$$

$$B = \tfrac{1}{2} \rho d^2 C_D \tag{17}$$

Here ρ is the fluid mass density, V_S is the volume of the sphere, and d is the diameter of the sphere. C_M and C_D are coefficients dependent on the Reynold's number of the fluid flow past the sphere. These coefficients are usually determined experimentally. In CABLE the following values are used [12]:

$$C_M = 1.0 \tag{18}$$

$$C_D = \begin{cases} 0.0 \text{ for } Re \leq 0.1 \\ 0.044 + 13.46/(Re)^{\frac{1}{2}} \text{ for } 0.1 < Re \leq 1000.0 \\ 0.47 \text{ for } 1000.0 < Re \leq 10^5 \\ 0.12 \text{ for } Re < 10^5 \end{cases} \tag{19}$$

where the Reynold's number Re is defined as

$$Re = \rho d |\underset{\sim}{V}| / \mu \tag{20}$$

where μ is the fluid viscosity.

The buoyancy forces are due to the hydrostatic pressure forces exerted on the sphere. These forces are normal to the surface of the sphere which is exposed to the fluid. Since CABLE assumes the cable links to be imbedded directly into the sphere, it modifies the usual buoyancy force on the sphere to account for the small portion of its surface which is shielded from the fluid. In general, then, the resultant buoyancy force is not directed exactly vertical.

19. Fluid Forces on the Towed Bodies

CABLE has the option of including up to three kinds of fluid forces on the towed bodies: 1) drag forces; 2) "added-mass" forces; and 3) buoyancy forces. The drag and added mass forces are calculated from a set of 25 hydrodynamic coefficients. The forms of these forces were developed from References [13, 14].

Before defining the drag and added mass forces, first consider the typical towed body shown in Figure 18.

IV. Definitions of Terms

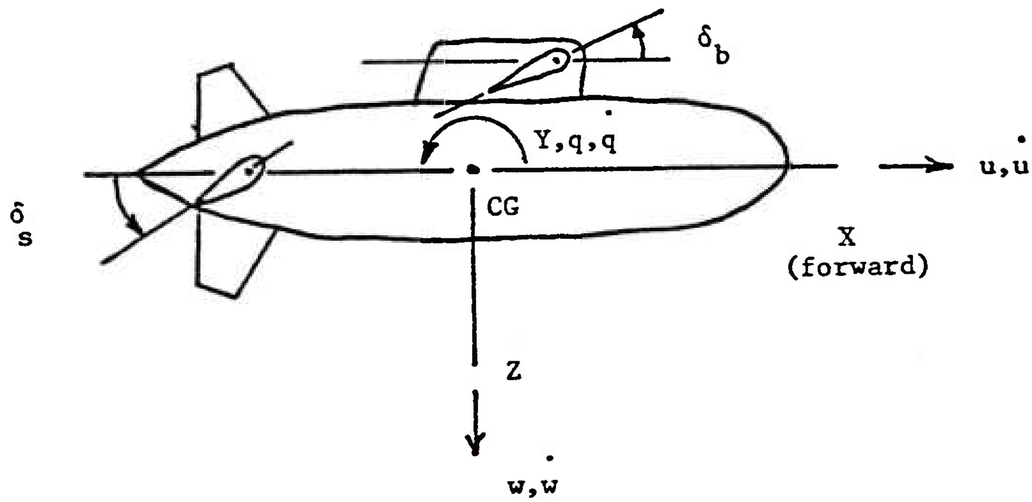

Figure 18. Typical Towed Body with Positive Coordinate, Velocity, Angular Velocity, and Angle Directions.

Here u and w represent the velocity components of the mass center CG of the body along the body-fixed directions, q represents the angular velocity of the body, and δ_b and δ_s represent the angle deflections of the bowplane and sternplane, respectively. The directions associated with the body-fixed X, Y, and Z coordinate axes are called the <u>axial</u>, <u>lateral</u>, and <u>normal</u> directions.

CABLE replaces the drag and added mass forces by a single force and a couple which are defined as follows:

Axial Force

$$F_x = \tfrac{1}{2}\rho\, \ell^4\, [X'_{qq} q^2] + \tfrac{1}{2}\rho\, \ell^3\, [X'_{\dot{u}} \dot{u} + X'_{wq} wq] + \tfrac{1}{2}\rho\, \ell^2\, [X'_{uu} u^2 + X'_{ww} w^2 + X'_{\delta_b} u^2 \delta_B^2 + X'_{\delta_s} u^2 \delta_s^2] \qquad (21)$$

IV. Definitions of Terms

Normal Force

$$F_z = \tfrac{1}{2}\rho\, \ell^4\, [Z'_{\dot q}\dot q] + \tfrac{1}{2}\rho\, \ell^3 [Z'_{\dot w}\dot w + Z'_{uq}uq + Z'_{q|w|}q|w|]$$

$$+ \tfrac{1}{2}\rho\, \ell^2\, [Z'_{uu}u^2 + Z'_{uw}uw + Z'_{\delta_b}u^2\delta_b + Z'_{\delta_s}u^2\delta_s + Z'_{w|w|}w|w|] \qquad (22)$$

Pitch (Lateral) Moment

$$M_Y = \tfrac{1}{2}\rho\, \ell^5\, [M'_{\dot q}\dot q] + \tfrac{1}{2}\rho\, \ell^4\, [M'_{\dot w}\dot w + M'_{uq}uq + M'_{q|w|}q|w|]$$

$$+ \tfrac{1}{2}\rho\, \ell^3\, [M'_{uu}u^2 + M'_{uw}uw + M'_{\delta_b}u^2\delta_b + M'_{\delta_s}u^2\delta_s \qquad (23)$$

$$+ M'_{w|w|}w|w|]$$

where ρ is the mass density of the fluid and ℓ is the axial length of the towed body. The X', Z', and M' with the appropriate subscripts are the hydrodynamic coefficients for the axial, normal, and lateral directions, respectively. (These coefficients must be supplied by the user on input.) It should be noted here that the body has been assumed symmetric with respect to the X-Z plane and that it is undergoing a fully submerged forward tow.

The bowplane and sternplane deflections, δ_b and δ_s, must also be specified by the user. These are not, however, "read in" with the normal input data, but are specified in SUBROUTINE CVSPEC. The subroutine supplied with CABLE simply sets the values of δ_b and δ_s to zero and returns to the calling segment. This subroutine may be easily replaced to give the deflections nonzero values.

IV. Definition of Terms

The subroutine statement must read:

```
SUBROUTINE CVSPEC (TIME, IBODY, IFL, U, W, Q, THETA, X, Z, DELS, DELB)
```

where the variables in the parameter list are defined as follows: (* - indicates the value is supplied by CABLE)

VARIABLE	MEANING
TIME*	Value of time in seconds
IBODY*	Integer body number of the towed body
IFL*	Integer specifying the towed body to be in Fluid 1 (IFL = 1) or Fluid 2 (IFL = 2).
U*	Axial component of the velocity of the mass-center of the towed body.
W*	Downward (Z) component of the velocity of the mass-center of the towed body
Q*	Angular velocity of the towed body
THETA*	The angle between the towed body axes and the inertial axes (positive rotation in the +Y).
X*	The X coordinate of the mass-center relative to the inertial frame.
Z*	The Z coordinate of the mass-center relative to the inertial frame.
DELS	Sternplane deflection (radians) (See Figure 18.)
DELB	Bowplane deflection (radians) (See Figure 18.)

IV. Definition of Terms

The values of DELS (δ_s) and DELB (δ_B) must be calculated and returned to CABLE.

Finally, since CABLE assumes that the center of buoyancy and the center of mass of the towed body do not necessarily coincide, it replaces the buoyancy forces by a force through the mass center of the body as well as a couple.

20. Weight Forces

The weight force may be represented on each cable link L_k by a single vertical (downward) force $\underset{\sim}{W}_k$ passing through the mass center G_k of L_k. If γ_k is the weight density per unit length of L_k, $\underset{\sim}{W}_k$ may be expressed as:

$$\underset{\sim}{W}_k = -\gamma_k \ell_k \underset{\sim}{k} \tag{24}$$

where ℓ_k is the length of L_k and where $\underset{\sim}{k}$ is the vertical unit vector shown in Figure 17.

Similarly, the weight forces on the towed spheres and towed bodies may be represented by single vertical forces passing through the center of the bodies with magnitude equal to their weights.

21. Units

CABLE allows the user to select either English or metric units for the input and output data. If English units are selected, the units are slugs, feet,

and seconds for mass, length, and time. However, inches are used for the link diameter and towed sphere diameter. If metric units are selected the units are kilograms, meters, and seconds with centimeters used for link diameter and towed sphere diameter.

22. Labels

CABLE allows the user to arbitrarily label or name the links and towed bodies, their reference points, and the towed spheres.

V. INPUT DATA

This part of the Manual describes the specific input data requirements of CABLE. The data itself is described in terms of "line images" such as would also appear on a computer card.

As noted earlier, the algorithms and code of CABLE are written in FORTRAN. Hence, the input data is to be submitted in the FORTRAN format. Integer data is to be entered in I5 format, and real data in either F10.3 or E10.3, unless otherwise specified. For example, if two real numbers are to be read on a given line, then 2F10.3 or 2E10.3 will be used. The order of the input data is in the same order as it is described below. The units of the input data are either English or metric, according to the option selected.

1. Heading or Title

The first line of input to CABLE contains a title which may be used to identify the particular data entered. It may contain up to 80 characters, and it will appear at the top of each computer output data page.

2. Options

CABLE has a number of user options to define the desired analysis. These options are selected by specifying integer values (usually 0, 1, 2, 3, 4, or 5) as follows:

V. Input Data

1) Units (See Section 21., Part IV): On the first line of the data, enter a 1 if English units are desired. Enter a 2 if metric units are desired.

2) Normal drag forces (See Sections 17, 18, 19., Part IV): Enter a 1 to include these forces. Enter a 0 to neglect these forces.

3) Tangential drag forces (See Sections 17, 18, 19., Part IV): Enter a 1 to include these forces. Enter a 0 to neglect these forces.

4) Added mass forces (See Sections 17, 18, 19., Part IV): Enter a 1 to include these forces. Enter a 0 to neglect these forces.

5) Bouyancy forces (See Sections 17, 18, 19., Part IV): Enter a 1 to include these forces. Enter a 0 to neglect these forces.

6) Gravity forces (See Section 20., Part IV): Enter a 1 to include these forces. Enter a 0 to neglect these forces.

7) Viscosities and fluid mass densities (See Sections 17, 18, 19., Part IV): Enter a 0 to use the default values coded in CABLE. See Table I. If values different from these default

values are desired, enter a 1. Then four lines of data must be entered, providing the following:

i) Viscosity of the first fluid (usually air) (lb.sec./ft^2 or N.sec./m^2).

ii) Mass density of the first fluid (slug/ft^3 or kg/m^3).

TABLE I. Default Values for Fluid Viscosities and Mass Densities

	English	Metric
Viscosity (air)	3.7188×10^{-7}(lb-sec)/ft^2	1.7802×10^{-5}(N-sec)/m^2
Mass (air) Density	2.378×10^{-3} slug/ft^3	1.2252 kg/m^3
Viscosity (water)	3.516×10^{-5}(lb-sec)/ft^2	1.6831×10^{-3}(N-sec)/m^2
Mass (water) Density	1.9856 slug/ft^3	1.0231×10^{3} kg/m^3

iii) Viscosity of the second fluid (usually water) (lb.sec./ft^2 or N.sec/m^2).

iv) Mass density of the second fluid (slug/ft^3 or kg/m^3).

8) Fluid velocities: CABLE has the option of allowing the fluids to have constant stream velocities in any direction. To use

this option, enter a 1. Next, enter two lines of data providing: the X and Z components relative to inertia space of the velocities of the two fluids (fluid 1 (air) on the first line, and fluid 2 (water) on the second line).

To decline this option, enter a 0. This means the fluids will have zero velocity.

9) Fluid Interface Level: CABLE has the option of allowing the fluid interface level (that is, the water level) to be located at some nonzero vertical distance below the mean ship frame. To use this option, enter a 1. Then, on the next line of input, enter the vertical distance (positive downward) from the mean ship frame. To decline this option, enter a 0. This means the fluid interface and the mean ship frame will be on the same level.

The set of options data will consume between 9 and 16 lines, depending upon whether viscosities, densities, velocities, and the fluid interface level are specified by the user.

V. Input Data

3. Number of Links

Following the input on user options, enter the number of cable links on a single line.

4. Individual Link Data

The next input data is a series of data sets describing the physical and geometrical properties of each link, as follows:

1) Link number (See Section 6., Part IV).

2) Label: Any name up to 20 characters in length.

3) Link Reference Point Label (or "joint" label) (See Section 4., Part IV): Any name up to 20 characters in length.

4) Link number of adjacent lower numbered link.

5) Link weight density (weight per unit length, lb/ft or N/m).

6) Link length (ft or m).

7) Link diameter (in or cm).

8) Initial configuration of the link. This line contains a single number representing θ, the angle of the link (in degrees) relative to its adjacent lower numbered link (See Sections 11. and 13., Part IV).

9) Initial motion of the link. This line contains a single number representing $\dot{\theta}$, the derivative of the initial angle of the link (in degrees/second).

Nine lines of data are required for each link.

5. Number of Towed Spheres

The link data is followed by analogous data for the towed spheres. The first line of towed sphere data contains the number of towed spheres.

6. Individual Towed Sphere Data

The next input data is a series of data sets describing the physical and geometrical properties of each towed sphere as follows:

1) Towed sphere number (See Section 6., Part IV).

2) Towed sphere label (up to 20 characters).

3) Link number of the adjacent towing link.

4) Towed sphere weight (lb or N).

5) Towed sphere diameter (in or cm).

Five lines of data are required for each towed sphere.

7. Number of Towed Bodies

The towed sphere data is followed by analogous data for the towed bodies. The first line of the towed body data contains the number of towed bodies.

8. Individual Towed Body Data

The next input data is a series of data sets describing the physical, geometric, and hydrodynamic properties of each towed body as follows:

1) Towed body number (See Section 6., Part IV).

2) Label: Any name up to 20 characters in length.

3) Towed body reference point label (or "joint" label) (See Sections 4., 5., and 16., Part IV): Any name up to 20 characters in length.

4) Link number of adjacent towing link (See Section 6., Part IV).

5) Towed body weight (lb or N).

6) Axial length of body (ft or m).

7) Towed body volume (ft^3 or m^3).

8) Towed body inertia (See Section 16., Part IV): (slug-ft^2 or N-m^2).

9) Mass center position vector. This line contains two numbers representing the body-fixed X and Z components of the position vector of the mass center of the towed body relative to the cable attach point (ft or m). Negative numbers indicate negative coordinate directions. (See Section 16., Part IV).

10) Center of buoyancy position vector. This line contains two numbers representing the body-fixed X and Z components of the position vector of the center of buoyancy of the towed body relative to its mass center (ft or m). Negative numbers indicate negative coordinate directions. (See Section 16., Part IV).

11) Initial configuration of the towed body. This line contains a single number representing Θ, the initial angle of the towed body (in degrees) relative to its adjacent towing link. (See Sections 12. and 13., Part IV).

12) Initial motion of the towed body. This line contains a single number representing $\dot{\Theta}$, the derivative of the initial angle of the towed body (in degrees/second).

13) Hydrodynamic coefficients for the towed body. The next six lines of input contain the values representing the hydrodynamic coefficients used to calculate the axial and normal forces and the pitch (lateral) moment on the towed body. They appear on the lines as follows:

Line 1: $X'_{\dot{u}}$, X'_{uu}, X'_{ww}, X'_{wq}, and X'_{qq}

Line 2: X'_{δ_b} and X'_{δ_s}

Line 3: $Z'_{\dot{w}}$, $Z'_{\dot{q}}$, Z'_{uu}, Z'_{uw}, and Z'_{uq}

Line 4: $Z'_{w|w|}$, $Z'_{q|w|}$, Z'_{δ_b}, and Z'_{δ_s}

Line 5: $M'_{\dot{w}}$, $M'_{\dot{q}}$, M'_{uu}, M'_{uw}, and M'_{uq}

Line 6: $M'_{w|w|}$, $M'_{q|w|}$, M'_{δ_b}, and M'_{δ_s}

(See Section 19., Part IV).

Eighteen lines of data are required for each towed body.

9. Motion of the Mean Ship Frame and the System Reference Point

The mean ship frame may have straight line motion relative to the inertial frame R. One variable representing the forward (or reverse) speed are used to describe the motion. Also, the system reference point Q may have arbitrary motion relative to the mean ship frame, requiring two additional variables. (See Section 7., Part IV).

For input, these variables are identified by the following integers:

V. Input Data

1 - Forward displacement (X) of the reference point Q relative to the mean ship frame (backward if negative).

2 - Vertical (downward) displacement (Z) of the reference point point Q relative to the mean ship frame.

3 - Forward (or reverse, if negative) speed of the mean ship frame relative to the inertial frame R. Note: If a precoded function is used to specify this motion, the mean ship frame is assumed to coincide with the inertial frame at t = 0.0.

The data describing these variables may be specified in two ways: 1) by using precoded functions and 2) by using acceleration profiles. (See Sections 8. and 9., Part IV.) The precoded functions are of the form:

$$f = f_0 + Ae^{bt}\cos(pt + \phi) \tag{25}$$

where f_0 + A, b, p, and ϕ are constants. The acceleration profiles are described in Section 8. of Part IV of the Manual.

The specific input data requirements are as follows: First, enter the number of these variables which are to have <u>nonzero</u> values during the motion. Then, for each of these variables enter its identifying integer (see above) in <u>column 1</u>. In <u>column 2</u> enter a 1 or a 2 depending on whether a precoded function or an acceleration profile is desired.

V. Input Data

If a precoded function is selected, enter the values of f_0, A, b, p, and ϕ on the next line.

Alternatively, if an acceleration profile is selected, enter the number of data points (up to 25) on the next line. This line, in turn, must then be followed by the same number of data lines as there are data points (one line per point). The first of these lines contains: i) the initial time, ii) the initial acceleration, iii) the initial speed, and iv) the initial displacement. The subsequent lines contain two numbers: i) the time and ii) the acceleration value.

If several variables have specified motion, their data is included in serial fashion.

10. Integration Options

The next data is a set of four numbers setting the parameters of the integration subroutine RKGS. These numbers are entered on a single line as follows: i) Integration starting time, ii) Integration ending time, iii) Integration time increment, and iv) Upper bound on the error. Note: If the integration time increment is input as a negative value, say -I, then CABLE will automatically reset the increment to $(2)^{-I}$.

11. Output Options

1) The next line contains the time increment for printing the computed data. Since printing this data at each integration step can produce an excessive amount of printed output, the print time increment is usually greater than the integration time increment.

2) At the beginning of the output data, CABLE lists a copy (or "echo") of the input data. The extent of the listing of computed data is a user option. To exercise this option, enter an integer (0,1,2,3,4) in column 1 according to the following printing priority:

0 - Prints all computed data: Position, velocity, and acceleration of the mean ship frame; Position, velocity, and acceleration of Q the system reference point; Orientation angles and their derivatives for each link and towed body (in degrees, degrees/second, and degrees/second/second); Position, velocity, and acceleration of the link, towed sphere, and towed body mass centers relative to inertia space; Position velocity, and acceleration of the connecting joints relative to the inertia space; Cable tension at the system reference point Q; and Cable tension at the connecting joints.

V. Input Data

1 - Prints as above for the option integer 0, except for the cable tension at the connection joints.

2 - Prints as above for the option integer 1, except for the cable tension at the system reference point.

3 - Prints as above for the option integer 2, except for the position velocity, and acceleration of the joints.

4 - Prints as above for the option integer 3, except for the position, velocity, and acceleration of the mass centers.

VI. EXAMPLE INPUT DATA

For an illustration of the input data consider the cable link system shown in Figure 19.

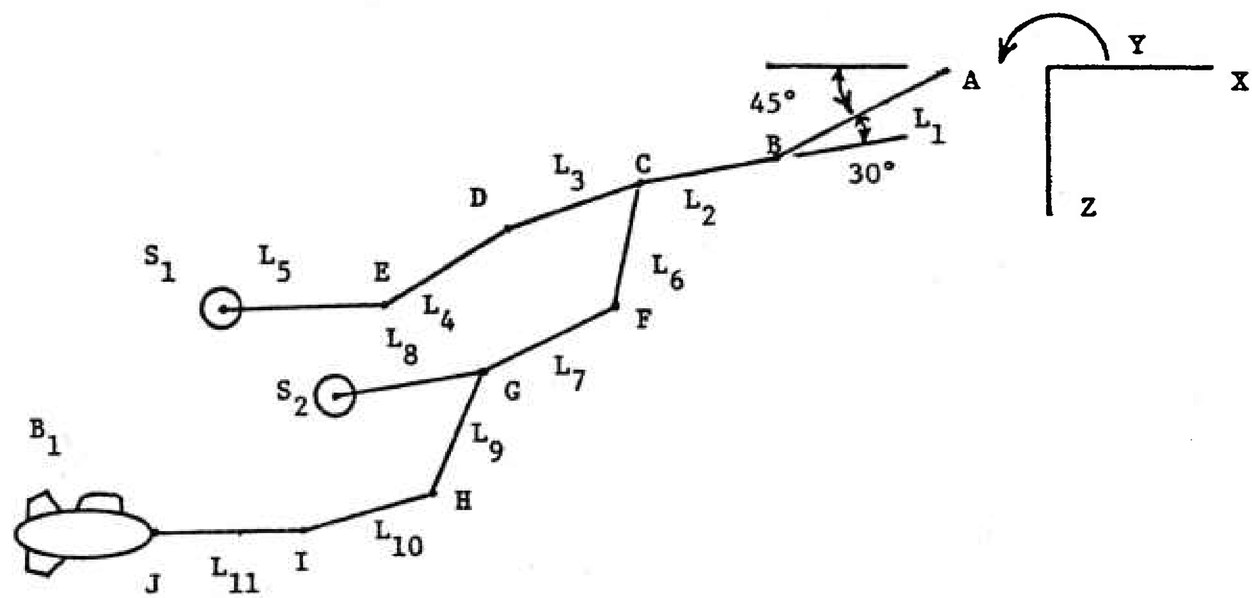

Figure 19. Example Cable Link System with Labels.

Let the eleven cable links be identical having length 2 ft, diameter 0.25 in., and weight density of 0.2 lb/ft. Let the two towed spheres (S_1 and S_2) have diameters 1.0 in. and 1.5 in. with weights of 0.5 lb and 1.688 lb. Let the towed body (B_1) be a sphere of diameter 2.0 in. ($0.1\overline{66}$ ft), volume 0.0024241 ft^3. weight 4 lb and inertia 3.4507×10^{-4} slug-ft^2. Finally let the reference point be on the surface of the sphere, and let the centers of mass and buoyancy both be located at the center of the sphere.

VI. Example Input Data

Let the mean ship frame have a forward motion defined by the acceleration profile shown in Figure 20. Let the initial forward ship speed be 5 ft/sec, and let the initial displacement be zero.

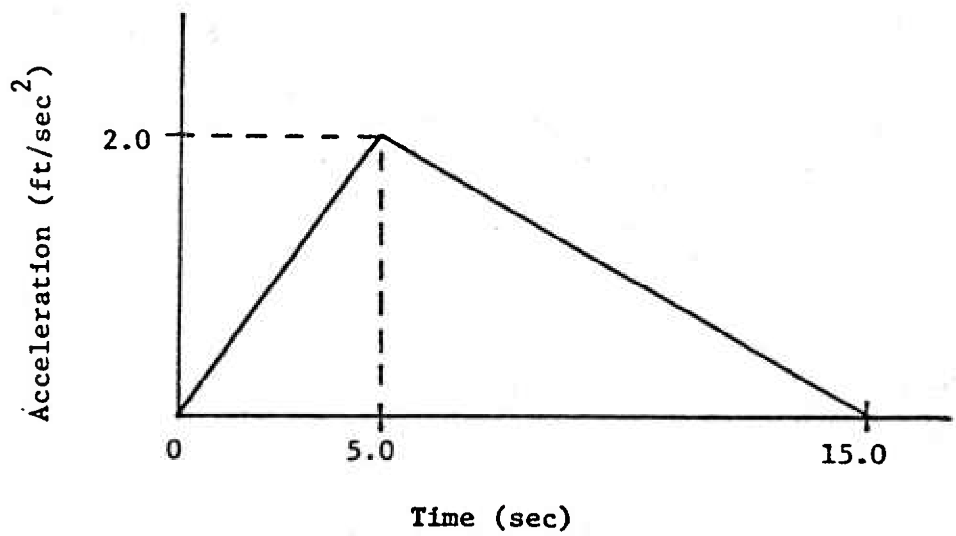

Figure 20. Acceleration Profile for Forward Mean Ship Frame Motion

Let the system reference point (point A) have oscillatory motion relative to the mean ship frame given by the expression

$$z = 0.5 \cos \pi t$$

Let the fluid level be 3 ft below the mean ship frame.

Let the links, spheres, and towed bodies be labelled as shown in Figure 19 and numbered as shown in Figure 21.

VI. Example Input Data

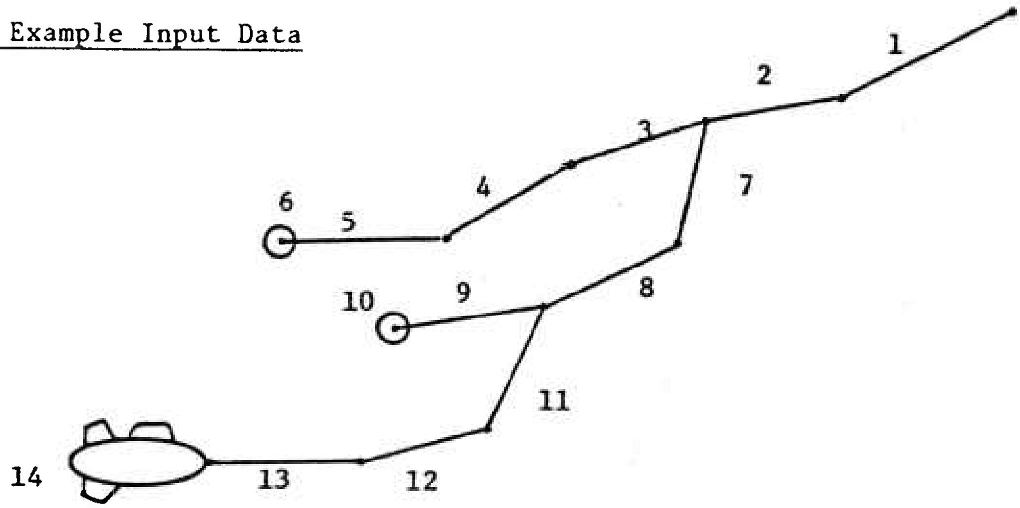

Figure 21. Example Cable Link System with Body Numbers

Let the system be moving in still air and calm water. Let gravity and fluid forces be acting and let the air and water viscosities and densities be the same as the default values in CABLE.

Finally, to illustrate the input of initial conditions, let link L_1 make an angle of 45° with the horizontal and let link L_2 make an angle of 30° with L_1 as shown in Figure 19. Let the initial angles of all the other links be zero (even though they are not depicted that way in Figure 19.)

The input data for the two-dimensional analysis of the motion is then as follows: (Note: The comments in parentheses are for illustration purposes only and should not appear in the normal FORTRAN input.)

VI. Example Input Data

Line Column Numbers

```
         1         2         3
123456789012345678901234567890123...

EXAMPLE INPUT DATA                           (Title)
    1                                        (English Units)
    1                                        (include normal drag)
    1                                        (include tangential drag)
    1                                        (include added mass effects)
    1                                        (include buoyancy forces)
    1                                        (include gravity forces)
    0                                        (use default fluid properties)
    0                                        (fluids are at rest)
    1                                        (specify by nonzero fluid
3.0                                           interface level)
   11                                        (number of cable links)
    1                                        (link body number)
L1                                           (link label)
A                                            (reference point label)
    0                                        (lower link)
0.2                                          (weight/length)
2.0                                          (length)
0.25                                         (diameter)
45.0                                         (initial orientation)
0.0                                          (initial angle derivatives)
    2                                        (next link body number and data)
L2
B
    1
0.2
2.0
0.25
-30.0
0.0
    3                                        (next link body number and data)
L3
C
    2
0.2
2.0
0.25
0.0
0.0
         1         2         3
12345678901234567890 1234...  0
```

VI. Example Input Data

Line Column Numbers

```
         1         2         3
123456789012345678901234567890123...

    4                                       (next link body number and data)
L4
D
    3
0.2
2.0
0.25
0.0
0.0
    5                                       (next link body number and data)
L5
E
    4
0.2
2.0
0.25
0.0
0.0
    7                                       (next link body number and data)
L6
C
    2
0.2
2.0
0.25
0.0
0.0
    8                                       (next link body number and data)
L7
F
    7
0.2
2.0
0.25
0.0
0.0
    9                                       (next link body number and data)
L8
G

         1         2         3
1234567890123456789012345...    0
```

VI. Example Input Data

Line Column Numbers

```
         1         2         3
123456789012345678901234567890123...
    8
0.2
2.0
0.25
0.0
0.0
   11                                        (next link body number and data)
L9
G
    8
0.2
2.0
0.25
0.0
0.0
   12                                        (next link body number and data)
L10
H
   11
0.2
2.0
0.25
0.0
0.0
   13                                        (next link body number and data)
L11
I
   12
0.2
2.0
0.25
0.0
0.0
    2                                        (number of towed spheres)
    6                                        (sphere body number)
S1                                           (label)
    5                                        (body number of lower link)
0.5                                          (weight)
1.0                                          (diameter)
   10                                        (next towed sphere body number
S2                                            and data)
    9
         1         2         3
1234567890123456789012345...  0
```

VI. Example Input Data

```
Line Column Numbers
          1         2         3         4
1234567890123456789012345678901234567890123...

1.688
1.5
    1                                              (number of towed bodies)
   14                                              (towed-body body number)
B1                                                 (body label)
J                                                  (joint label)
   13                                              (lower link body number)
4.0                                                (weight)
0.1666667                                          (axial body length)
0.0024241                                          (volume)
 3.4507E-4                                         (inertia)
-0.0833333 0.0                                     (c.m. position vector)
0.0        0.0                                     (c.b. position vector)
0.0                                                (initial angle)
0.0                                                (initial angle derivative)
-0.52     -0.46     -0.23      0.0       0.0
0.0       0.0
-0.52     0.0       0.0        -0.46     0.0       (hydrodynamic coefficients)
0.0       0.0       0.0
0.0       0.0       0.0        0.0       0.0
0.0       0.0       0.0        0.0
    2                                              (number of specified variables)
21                                                 (variable 2 is specified with a
0.0       0.5       0.0        3.1416    0.0        precoded function)
32                                                 (variable 3 is specified with an
0.0       0.0       5.0        0.0                  acceleration profile)
5.0       2.0
15.0      0.0
0.0       20.0      0.25       0.001               (integration parameters)
0.5                                                (time increment for printing data)
0                                                  (output option--print all data)
          1         2         3
1234567890123456789012345...
```

VII. EXAMPLE OUTPUT

Besides providing an "echo" of the input data prior to numerical integration, CABLE provides output data at specified instants of time. Both the printing interval size as well as the amount of printout received at the end of the interval are user options. Shown in Figures 22 and 23 is the standard printout for an output printing priority of zero.

```
                    CABLE TEST --  TOWED BODY (SPHERE) IN A FLUID STREAM (6 FT. CABLE)
 TIME =    1.0000          SECONDS                                                                  INTERVAL DIVISIONS =    0
 NUMBER OF INTEGRATION STEPS =   153

                                              SPECIFIED MOTION

        MEAN SHIP FRAME                                                      SYSTEM REFERENCE POINT
                                                                        (RELATIVE TO THE MEAN SHIP FRAME)

X-POSITION COORDINATE  =     5.0000                        Z,X-POSITION COORDINATES    =     0.          0.
FORWARD SPEED          =     5.0000                        Z,X-VELOCITY COMPONENTS     =     0.          0.
FORWARD ACCELERATION   =     0.                            Z,X-ACCELERATION COMPONENTS =     0.          0.

 RELATIVE ORIENTATION ANGLES OF THE CABLE LINKS IN DEGREES

 BODY( 1)     3.5314          BODY( 5)     .27835          BODY( 9)     .73735
 BODY( 2)     .14365          BODY( 6)     .34752          BODY(10)     .99884
 BODY( 3)     .18056          BODY( 7)     .43675          BODY(11)    1.3776
 BODY( 4)     .22022          BODY( 8)     .55038          BODY(12)    2.2412

 RELATIVE ORIENTATION ANGLES OF THE TOWED BODIES IN DEGREES

 BODY(13)   -11.044

 DERIVATIVES OF THE RELATIVE ORIENTATION ANGLES OF THE CABLE LINKS IN DEGREES/SECOND

 BODY( 1)     2.5664          BODY( 5)     .11245          BODY( 9)     .12482
 BODY( 2)     .15642          BODY( 6)     .22155          BODY(10)     .16463
 BODY( 3)     .11664          BODY( 7)     .12827          BODY(11)   7.23131E-02
 BODY( 4)     .19754          BODY( 8)     .21699          BODY(12)  -1.39970E-02

 DERIVATIVES OF THE RELATIVE ORIENTATION ANGLES OF THE TOWED BODIES IN DEGREES/SECOND

 BODY(13)    -4.0641

 SECOND DERIVATIVES OF THE RELATIVE ORIENTATION ANGLES OF THE CABLE LINKS IN DEGREES/(SECOND)**2

 BODY( 1)   -7.3927           BODY( 5)   -23.317           BODY( 9)    -8.7514
 BODY( 2)    12.791           BODY( 6)    20.097           BODY(10)     5.1409
 BODY( 3)   -21.574           BODY( 7)   -16.697           BODY(11)    -2.7793
 BODY( 4)    24.554           BODY( 8)    12.754           BODY(12)     1.1682

 SECOND DERIVATIVES OF THE RELATIVE ORIENTATION ANGLES OF THE TOWED BODIES IN DEGREES/(SECOND)**2

 BODY(13)     4.0061
```

Figure 22. Example Output

MASS CENTER DATA (RELATIVE TO THE INERTIAL FRAME)

	POSITION COMPONENTS Z	X	VELOCITY COMPONENTS Z	X	ACCELERATION COMPONENTS Z	X
MASS-CENTER LINK 1:	.12833E-01	4.7921	.93141E-02	5.0006	-.26855E-01	-.12305E-02
MASS-CENTER LINK 2:	.41917E-01	4.3311	.30652E-01	5.0019	-.29907E-01	-.37442E-03
MASS-CENTER LINK 3:	.73690E-01	3.8478	.54090E-01	5.0035	-.71161E-01	-.20891E-02
MASS-CENTER LINK 4:	.10731	3.3635	.78967E-01	5.0052	-.99126E-01	-.25441E-02
MASS-CENTER LINK 5:	.14408	2.8643	.10591	5.0072	-.12603	-.33115E-02
MASS-CENTER LINK 6:	.18374	2.3639	.13440	5.0094	-.16713	-.46667E-02
MASS-CENTER LINK 7:	.22633	1.8684	.16409	5.0120	-.19271	-.53501E-02
MASS-CENTER LINK 8:	.27204	1.3862	.19446	5.0149	-.23616	-.72770E-02
MASS-CENTER LINK 9:	.32413	.89580	.22681	5.0183	-.26394	-.83128E-02
MASS-CENTER LINK 10:	.38404	.40232	.26059	5.0224	-.30715	-.11014E-01
MASS-CENTER LINK 11:	.45381	-.86993E-01	.29511	5.0273	-.33981	-.13331E-01
MASS-CENTER LINK 12:	.54739	-.61698	.33276	5.0340	-.38232	-.17971E-01
M.C. TOWED BODY	.60315	-.90263	.35303	5.0380	-.40257	-.20432E-01

REFERENCE POINT DATA (RELATIVE TO THE INERTIAL FRAME)

	POSITION COMPONENTS Z	X	VELOCITY COMPONENTS Z	X	ACCELERATION COMPONENTS Z	X
SYSTEM REF. POINT :	0.	5.0000	0.	5.0000	0.	0.
END OF LINK 1:	.25665E-01	4.5841	.18628E-01	5.0011	-.53711E-01	-.24771E-02
END OF LINK 2:	.58168E-01	4.0781	.42676E-01	5.0027	-.61043E-02	.17282E-02
END OF LINK 3:	.89212E-01	3.6175	.65504E-01	5.0042	-.13622	-.59044E-02
END OF LINK 4:	.12541	3.1095	.92429E-01	5.0062	-.62034E-01	.81618E-03
END OF LINK 5:	.16276	2.6190	.11939	5.0082	-.19003	-.74391E-02
END OF LINK 6:	.20472	2.1087	.14941	5.0107	-.14424	-.18944E-02
END OF LINK 7:	.24795	1.6281	.17877	5.0133	-.24119	-.88058E-02
END OF LINK 8:	.29614	1.1443	.21015	5.0164	-.23113	-.57482E-02
END OF LINK 9:	.35212	.64729	.24347	5.0202	-.29676	-.10877E-01
END OF LINK 10:	.41597	.15735	.27772	5.0247	-.31755	-.11152E-01
END OF LINK 11:	.49164	-.33133	.31250	5.0300	-.36206	-.15510E-01
M.C. TOWED BODY	.60315	-.90263	.35303	5.0380	-.40257	-.20432E-01

TENSION AT SYSTEM REFERENCE POINT (POSITIVE INDICATES TENSION)

.45144

TENSIONS AT ALL OTHER REFERENCE POINTS (POSITIVE INDICATES TENSION)

END OF LINK 1:	.44254
END OF LINK 2:	.43169
END OF LINK 3:	.42180
END OF LINK 4:	.41089
END OF LINK 5:	.40033
END OF LINK 6:	.38933
END OF LINK 7:	.37895
END OF LINK 8:	.36847
END OF LINK 9:	.35767
END OF LINK 10:	.34698
END OF LINK 11:	.33628
M.C. TOWED BODY	.33045

Figure 23. Example Output

APPENDIX

SUMMARY OF INPUT DATA REQUIREMENTS

This Appendix to the Manual provides an abbreviated summary of the input data requirements for a quick reference.

1. Heading or Title: Heading of up to 80 characters.

2. Options: As follows:

    1) Units:

        Enter 1 for English units.

        Enter 2 for metric units.

    2) Normal drag forces:

        Enter 1 to include the forces.

        Enter 0 to neglect the forces.

    3) Tangential drag forces:

        Enter 1 to include the forces.

        Enter 0 to neglect the forces.

    4) Added mass forces:

        Enter 1 to include the forces.

        Enter 0 to neglect the forces.

5) Buoyancy forces:

Enter 1 to include the forces.

Enter 0 to neglect the forces.

6) Gravity forces:

Enter 1 to include the forces.

Enter 0 to neglect the forces.

7) Viscosities and fluid mass densities:

Enter 0 to use the default values.

Enter 1 to use substitute values entered on four subsequent data lines as follows:

i) Viscosity of the first fluid

ii) Mass density of the first fluid

iii) Viscosity of the second fluid

iv) Mass density of the second fluid

8) Fluid velocities:

Enter 0 for zero fluid velocities.

Enter 1 for constant fluid velocities. Then, on the next two lines, enter for the two fluids, the X and Z components of the velocities.

9) Fluid Interface Level:

Enter a 0 for a zero interface level.

Enter a 1 for a nonzero interface level.

Then, on the next line, enter a distance.

3. Number of links: Enter number.

4. Individual link data: As follows:

1) Link number
2) Label: Up to 20 characters
3) Link reference point label: Up to 20 characters
4) Link number of adjacent lower numbered link
5) Link weight density (per unit length)
6) Link length
7) Link diameter
8) Initial configuration of the link: Enter Θ the initial angle (in degrees)
9) Initial motion of the link: Enter $\dot{\Theta}$ the derivative of the initial angle (in degrees/second).

5. Number of towed spheres: Enter number.

6. Individual towed sphere data: As follows:

   1) Towed sphere number
   2) Towed sphere label: up to 20 characters
   3) Link number of adjacent towing link
   4) Towed sphere weight
   5) Towed sphere diameter

7. Number of towed bodies: Enter number.

8. Individual towed body data: As follows:

   1) Towed body number
   2) Label: up to 20 characters
   3) Towed body reference point label: up to 20 characters
   4) Link number of adjacent towing link
   5) Towed body weight
   6) Towed body axial length
   7) Towed body volume
   8) Towed body inertia
   9) Towed body mass center position vector relative to cable attach point (X, Z components)
   10) Buoyancy center position vector relative to the mass center of the towed body (X, Z components)

11) Initial configuration of the towed body: Enter Θ the initial angle (in degrees)

12) Initial motion of the towed body: Enter $\dot{\Theta}$ the derivative of Θ the initial angle (in degrees/second).

13) Hydrodynamic coefficients for the towed body: Enter as follows:

Line 1: $X'_{\dot{u}}$, X'_{uu}, X'_{ww}, X'_{wq}, and X'_{qq}

Line 2: X'_{δ_b} and X'_{δ_s}

Line 3: $Z'_{\dot{w}}$, $Z'_{\dot{q}}$, Z'_{uu}, Z'_{uw}, and Z'_{uq}

Line 4: $Z'_{w|w|}$, $Z'_{q|w|}$, Z'_{δ_b}, and Z'_{δ_s}

Line 5: $M'_{\dot{w}}$, $M'_{\dot{q}}$, M'_{uu}, M'_{uw}, and M'_{uq}

Line 5: $M'_{w|w|}$, $M'_{q|w|}$, M'_{δ_b}, and M'_{δ_s}

9. Motion of the mean ship frame and system reference point:

Enter data only for nonzero variables among the following:

Identification Number	Variable
1	Forward displacement of reference point Q relative to the mean ship frame
2	Downward (vertical) displacement of the reference point Q relative to the mean ship frame
3	Forward speed of the mean ship frame

SUMMARY OF INPUT DATA REQUIREMENTS

First enter the number of nonzero variables which are to be specified. On the next line enter the variable identification number in column 1, and in column 2 enter: 1 for a precoded function; 2 for an acceleration profile.

If a precoded function is selected, values of f_0, A, B, p, and ϕ on the subsequent line. (See Equation (25).)

If an acceleration profile is selected, enter the following data lines:

1) Number of points (up to 25)
2) Initial time; Initial acceleration; Initial speed; Initial displacement (all on one line).
3) Time; acceleration (one line for each remaining point).

8. Integration Options: Enter on a single line: i) starting time; ii) ending time; iii) time increment; and iv) error bound.

9. Output Options:

1) Enter the printing time increment
2) Enter number from 0 to 4 in column 1 as follows:

SUMMARY OF INPUT DATA REQUIREMENTS

0 - Print all data.

1 - Print all but tension at the joints.

2 - Print as above except for tension at the reference point Q.

3 - Print above except for joint kinematics.

4 - Print as above except for mass center kinematics.

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